Fermilab

Linac Upgrade Note #LU-218

Beam Diagnostics for the Fermilab 400 MeV Linac Upgrade

Elliott McCrory

May 10, 1993

I. Introduction

The Fermilab 400 MeV Linac Upgrade incorporates extensive beam diagnostics. This will help speed up the commissioning process and also insure the long-term stability of the accelerator.

Table 1, Beam Diagnostics for the 400 MeV Fermilab Linac

Diagnostics Device	Abbrev.	Short Description
Beam Position Monitor	BPM	Transverse position of the beam throughout the linac
Dipole Trim Magnet	Trim	Correction of the transverse position
Resistive Wall-Current Monitor	RWCM	1. Beam Current measurement 2. Time-of-flight, Δt 3. Crude (2 GHz) Bunch-length measurement
Bunch-Length Detector	BLD	Accurate (300 GHz BW) bunch-length measurement
Toroid	-	We have a single conventional toroid in Module 7

The beam diagnostics and their basic capabilities are listed in the Table 1.

This document is organized as follows. The layout of the diagnostic elements in the Linac is presented. Then each type of element is described in moderate detail. For each type of element, a mechanical and/or an electrical drawing is referenced. Also, a few sentances on the principle of operation of each device is presented. Next, the Lock-Out, Tag-Out (LOTO) procedures are referenced. And finally, an overview of the control system requirements for the diagnostics is presented.

II. Overview

The arrangement of the diagnostics devices and the quadrupole magnets is presented in Table 2. The space between the accelerating sections is consistently $3\beta\lambda/2$. ($3\lambda/2$=55.9 cm; $0.457 < \beta < 0.714$ for the Linac, which yields spaces from 25.6 to 39.9 cm.) This is fairly restrictive, particularly in Module 1. The diagnostics have been designed to take advantage of the limited space available. The basic layout of the diagnogstics can be found in drawing ME-62910 (16 sheets).

II.A. Beam Position Monitors

BPMs are located inside most of the Linac Upgrade quadrupoles. The quads in which there is no BPM are: Q01 (before first transistion section cavity, but there is a BPM at the end of the old Linac), Q14 (quad following module 1) and Q24. The basic mechanical drawing for the BPMs is MC-61354. The BPM rf module electronics layout is given in drawing ED-281074.

Table 2, Layout of the Beam Diagnostics for the 400 MeV Linac Upgrade

Module/ Section	Diagnostics Elements	Module/ Section	Diagnostics Elements
0/0	B'SWDQ	4/1	BQS
0/1	BQWS	4/2	BQS
0/2	BQWSDSBQ	4/3	BQW
1/1	BQS	4/4	RBQ
1/2	BQW	5/1	BQS
1/3	BQW	5/2	BQS
1/4	RQ	5/3	BQW
2/1	BQS	5/4	RBQ
2/2	BQS	6/1	BQS
2/3	BQW	6/2	BQS
2/4	RQ	6/3	BQW
3/1	BQS	6/4	RBQW
3/2	BQS	7/1	BQS
3/3	BQW	7/2	BQS
3/4	RBQ	7/3	TBQW
		7/4	BQWL

Key:
B = BPM (29, +1 old style)
Q = Quad (32)
W = Wire scanner (13)
L = bunch-Length detector (3)
S = Steering trim (17)
T = conventional Toroid (1)

II.A.1 Principle of Operation

A simplistic model is rather accurate for understanding a BPM: as the beam gets closer to a plate, the current induced on that plate, from the charge on the beam, grow larger. Conversely, as the beam gets farther from a plate, that current gets smaller. Since the instantaneous beam current ca also change, it is most accurate to determine the position from either the ratio of the two opposite ports, or the difference/sum of the opposite plates. This is what the BPM rf module does.

The electrical center is measured to be within a few mils (0.001") of the mechanical center for each of the BPM.

II.B Dipole Trim Magnets

Trims are located throughout the Upgraded Linac to correct the trajectory of the ion beam through the accelerator. These iron-core magnets are significantly stronger than an air-core magnet of similar dimensions: we can achieve approximately 600 Gauss peak field from 5A of current. According to the Preliminary Design report, it is expected that we will need about 1.0 milliradians of deflection at each trim magnet in order to correct for anticipated alignment errors. All magnets have at least 2.3 mr of deflection (at 5 A). Table 3 shows the specifications of the magnets to be installed. There are three types of trim magnets built; they have been designed to entirely fit into the relevant spaces. The overall lengths are 48 mm, 64 mm and 89 mm.

Mechanical drawings exist for the iron pieces of the magnets; they are MB-300811 through MB-300816 (six drawings). The 16-gauge wire which is wound around each iron piece was done on a slow lathe in the Linac Basement Machine Shop by Linac Dept. personnel. The winding chart for

Table 3, Location and Strengths of Dipole Trim Steering Magnets

Module/ Section	Overall Length	Beam Energy	Deflection @ 5A
0/1	48 mm	116 MeV	2.5 mr
0/2	64	116	3.1
0/3	64	116	3.1
0/3	64	116	3.1
1/1	48	125.1	2.4
2/1	64	161.2	2.7
2/2	64	170.6	2.7
3/1	64	199.7	2.5
3/2	89	209.5	2.9
4/1	89	239.9	2.8
4/2	89	250.1	2.7
5/1	89	281.5	2.6
5/2	89	292.1	2.6
6/1	89	324.4	2.5
6/2	89	335.2	2.5
7/1	89	368.1	2.4
7/2	89	379.1	2.4
7/4	89	401.5	2.3

Table 4. Winding Chart for Linac Upgrade Trim Magnets

Layer #	Turns this layer	Total # of turns
1	53	53
2	50	103
3	49	152
4	46	198
5	45	243
6	42	285
7	41	326
8	38	364
9	37	401
10	34	435
11	33	468
12	30	498
13	29	527
14	26	553

all three types of magnets is given in Table 4.

II.C Wire Scanners

The wire scanners for the Upgraded Linac are specified in drawing MD-300032. Each unit contains three measurement wires: one for measuring the X beam profile, one for Y and one at 45° with respect to X and Y, which is referred to as the U wire. The motion of the wire is controlled by a Parker Compumotor motor, model RM57-51 and a Parker Compumotor controller, model PK2.

The readout of the wires and the motor position goes through a special buffer/amplifier box built at Fermilab. The circuit for this box is shown in drawing 0231.00-EC-281725.

II.C.1 Principle of Operation

The passage of the ion beam through the 0.004-inch tungsten wire induces a voltage on the wire (due to the loss of electrons from the molecular lattice of the wire). This voltage is brought out to the electronics by conventional RG58 cabling and plugged into the buffer box. The first element in the buffer box is a 15 MHz low-pass filter, to remove the 200 MHz noise on the signal. Then the signal is amplified by 20 dB and driven into the sample-and-hold and digitizer in the control system. The voltage measured from each wire is proportional to the intensity of the beam passing through the wire. As the motor moves through the beam, the amount of beam intercepting the wire changes in proportion to the shape of the beam, thus producing a profile of the beam. The motor moves the wire rather slowly: about 1 cm per second.

The X wire is a vertical wire and moves horizontally through the beam. The information obtained from the U wire eliminates the mirror ambiguity from measureing only the orthogonal components of the beam at X and Y.

II.D Resistive Wall-Current Monitor

At the ends of each module, we have installed a RWCM. The utility of this device is threefold. (1) We measure the beam current; (2) we measure the phase of the beam with respect to the rf phase for the Δt measurements and (3) we obtain some crude bunch-length information. The mechanical layout of the RWCM is shown in drawing MB-300822 The toroid readout NIM module is shown in the circuit 0281-ED-281746. A complete list of the relevant drawings is given in internal note LU-210.

II.D.1 Principle of Operation

A RWCM operates similarly to a BPM: converting the beam-induced wall currents into a time-sensitive voltage. The RWCM, however, has a ceramic gap directly in the beam pipe which entirely encircles the beam pipe. This gap is lined with small resistors and the voltage across these resistors is what is measured. The bandwidth of this signal is expected to be a few GHz. The gap is enclosed in a containment vessel to prevent external rf fields from affecting the signal. At the outside of the containment vessel, has been inserted ferite material. Wire is wound around this ferite so that beam passing through the ferite ring induces a magnetic field in the ferite; the changing magnetic field induces a current in the coiled wire, which is measured to determine the beam current. A small winding of calibration wire is used to determine the absolute calibration of the coil. We expect better than 5% absolute accuracy from this toroid.

II.E Bunch-Length Detector

Because the velocity of the linac beam is always substantially less than the speed of light, it is not possible to obtain an accurate or a detailed measurement of the bunch length from wall currents. To solve this problem, we have designed a BLD which will be able to measure the length of the ion-beam bunch to an accuracy of about 1 degree at 805 MHz. This corresponds to a time resolution of about 3 picoseconds, or a bandwidth of about 300 GHz.

Because of budget limitation, we are only able to build three of these devices at this time. One will go in the 400 MeV are, just downstream of Module 7. The other two will be put in the transition section.

The mechanical design of this device can be found in drawing ME-300677. The high-voltage power supplies used for this device are Glassman HV model PS/MJ15N100-11. The wire target is move by our custom actuator, which is driven by a Parker Compumotor motor model RM57-51 with a Parker Compumotor controller model PK2. The electron detector is a Hamamatsu model R5150

Electron Multiplier. The high-voltage for this device is supplied by a Bertan model Model 303 HVPS.

II.E.1 Principle of Operation

A brief overview of the operation of the BLD is presented here. Beam passing through the tungsten wire target causes secondary electrons to be liberated from the wire. The negative high voltage on the wire accelerates these electrons, and some of them pass through the rf deflector/einsel lens. The deflector, oscillating at the 4th harmonic of the beam-bunching frequency, sweeps an image of the electron source (the wire) across the back plane of the device. A slit in the center of the back-plane selects some of these electrons. The electrons which pass through the slit are amplified by an electron multiplier tube to generate a speedy signal which is digitized by the control system. The density of the electrons which pass through the slit is therefore proportional to the density of the incident ion beam for a particular rf phase angle. A more detailed description can be found in "Diagnostics for the 400 MeV Fermilab Linac," 1992 Accelerator Instrumentation Workshop, Berkeley, CA, by E. McCrory.

III. Interface to the Control System

The inteface to the control system for each of the diagnostics devices is outlines here.

III.A BPM

The BPMs are read out through a fast (1 to 5 MHz) digitizer into dynamic VME memory. The quick digitizer was designed at Fermilab, but the model number of the device we are using is from LeCroy Corp, 1164 Quick Digitizer. A single reading, representing either the central value of the position or the average value of the position, is the scalar value relayed to the observer in the Main Control Room. The conversion from voltage to absolute position within the beam pipe aperture is accomplished through linear scaling constants. The value of the response of the BPM electronics to beam has been measured through the calibration of the BPM and of the rf modules. The absolute position is measured with the beam, with a reasonable first guess derived from the calibration.

III.B Trim Magnets

The trim magnets use only the digitizers and the analog outputs of the Smart Rack Monitor. The analog input is calibrated to 10V input for 6A output. The output of the power supply is 10V for 6A.

III.C Wire Scanners

The wire scanners, as described above, interface to the control system through a specially built buffer/amplifier box.

III.D RWCM

The RWCMs are used in several ways. The toroid signal is patched into the NIM module, which buffers and amplifies the toroid signal and then is fed into a sample-and-hold chassis, which is triggered at beam time. The fast signal comes out of the tunnel on a large heliax-type cable, into the Linac Utilities basement, where it is connected to a conventional temperature stabilized 3/8" heliax which runs into the Diagnostics Room in the Linac Gallery. The signals from all of the RWCMs and some of the BPMs from the old part of the linac are distributed among three 8-way swithces so that any group of three signals can be selected to make the Δt-type measurement. The common conductor of the switch goes into a specially-built phase detector, as described above. The two outputs of the phase detector goes into a sample-and-hold chassis and is then digitized by a SRM. The arctan() function is performed by the application program.

III.E BLD

The BLDs have several connections with the control system. Each HVPS is individually controlled through a voltage setting (10V from the D/A for 15.0 KV on the supply) using a conventional D/A on the SRM. The current limit for all the HVPSs (10V for 1 milliAmp current limit) is set by a variable voltage source near the power supplies (it was decided that the relatively expensive D/A resources were not necessary for this functionality). Note that the HV on the focusing plates are independantly controllable, so that the steering of the secondary electron beam is acheived. The filament current, used for setting up the device, is done manually, off-line. The output current from the electron detector is put into a sample-and-hold chassis and digitized by an SRM.

IV. Procedures

Two LOTO procedures are relevant for the diagnostics: (1) When any diagnositic element needs removal and/or servicing beyond simple cable service, then it is necessary to observe the LOTO policy for the quadrupole magnet power supplies. (2) The BLD contains several high voltage connections, the power supplies for which need to be locked out when the BLD is serviced. Only the Quad lockout procedure has been written at this time: "Linac High Energy Pulsed Quads, ADDP-LI-0019."

V. Commissioning the Individual Diagnostics Elements

Except for the BPMs, all of the beam diagnostics need no explicit commissioning, other than routine checkout of the power supplies and/or the control/readout through the control system.

The BPMs have been calibrated already, but it is anticipated that we will need to use the beam to verify and/or change these calibration constants. In particular, the center of a BPM can be found by using the fact that each BPM sits inside a quadrupole magnet. Simply, we plan to steer the beam, using the trim magnets available to us, until the beam is not steered by changing that quad's gradient.

VI. Training

It is anticipated that no traing specific to the beam diagnostics will be necessary.